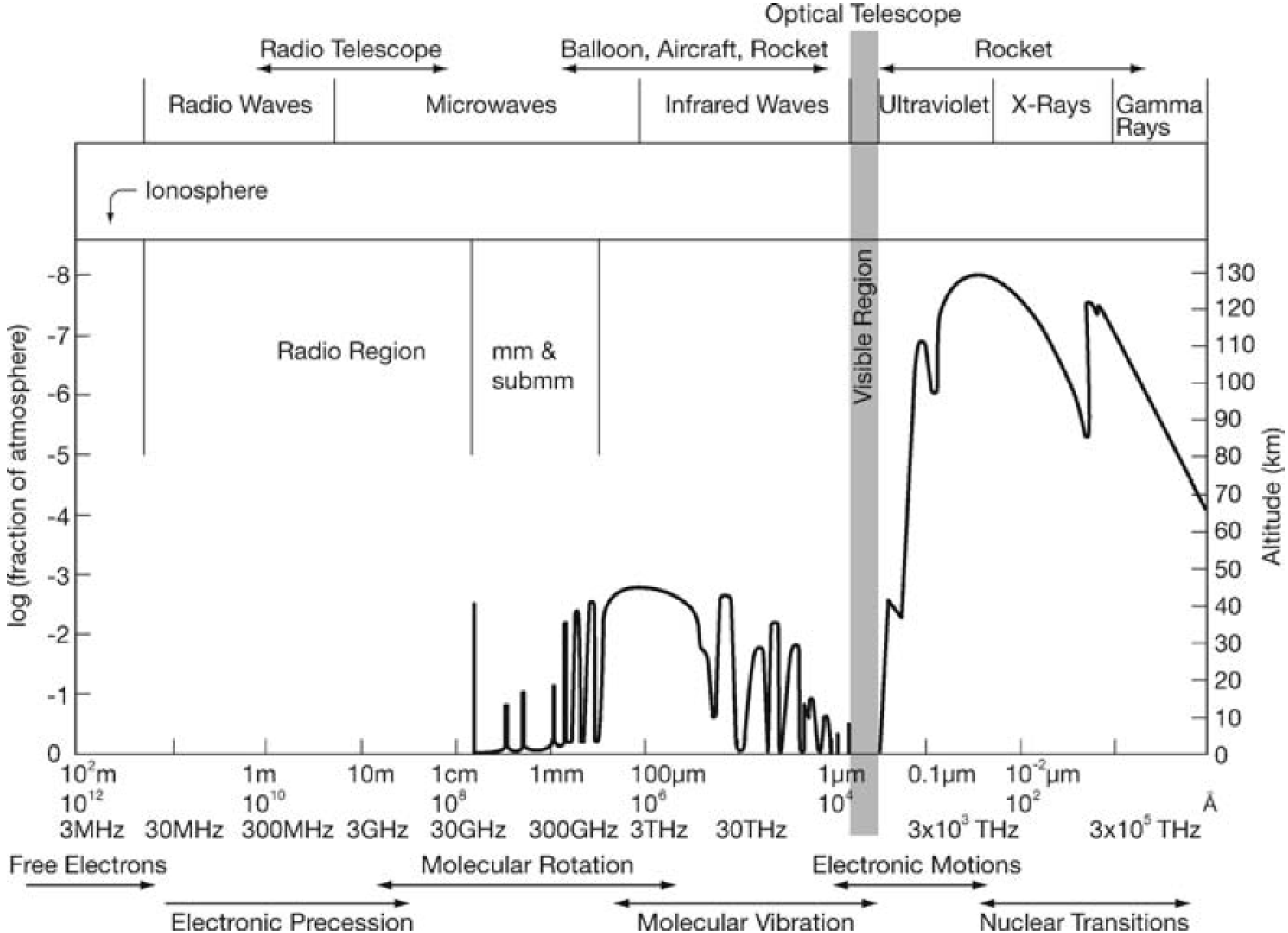
- Single dish radio telescopes

Astronomical Techniques II : **Lecture 2**

Ruta Kale

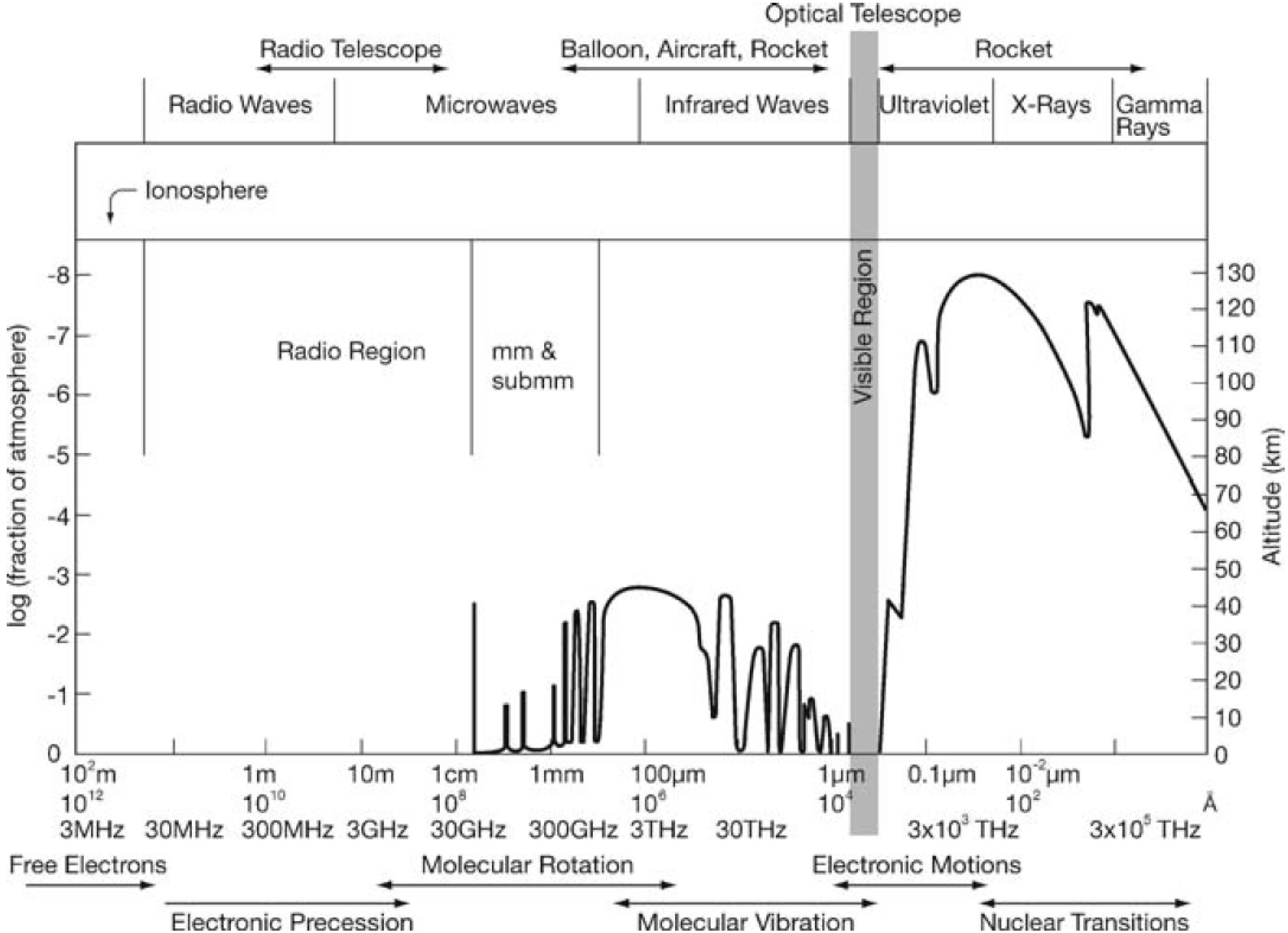
Essential Radio Astronomy (Chp 3)
Low Frequency Radio Astronomy (Chp. 3)
Tools of radio astronomy, Wilson, et al.

The radio window



The radio window

~15 MHz to ~1.5 THz



The radio window

~15 MHz to ~1.5 THz

Low frequency cut-off

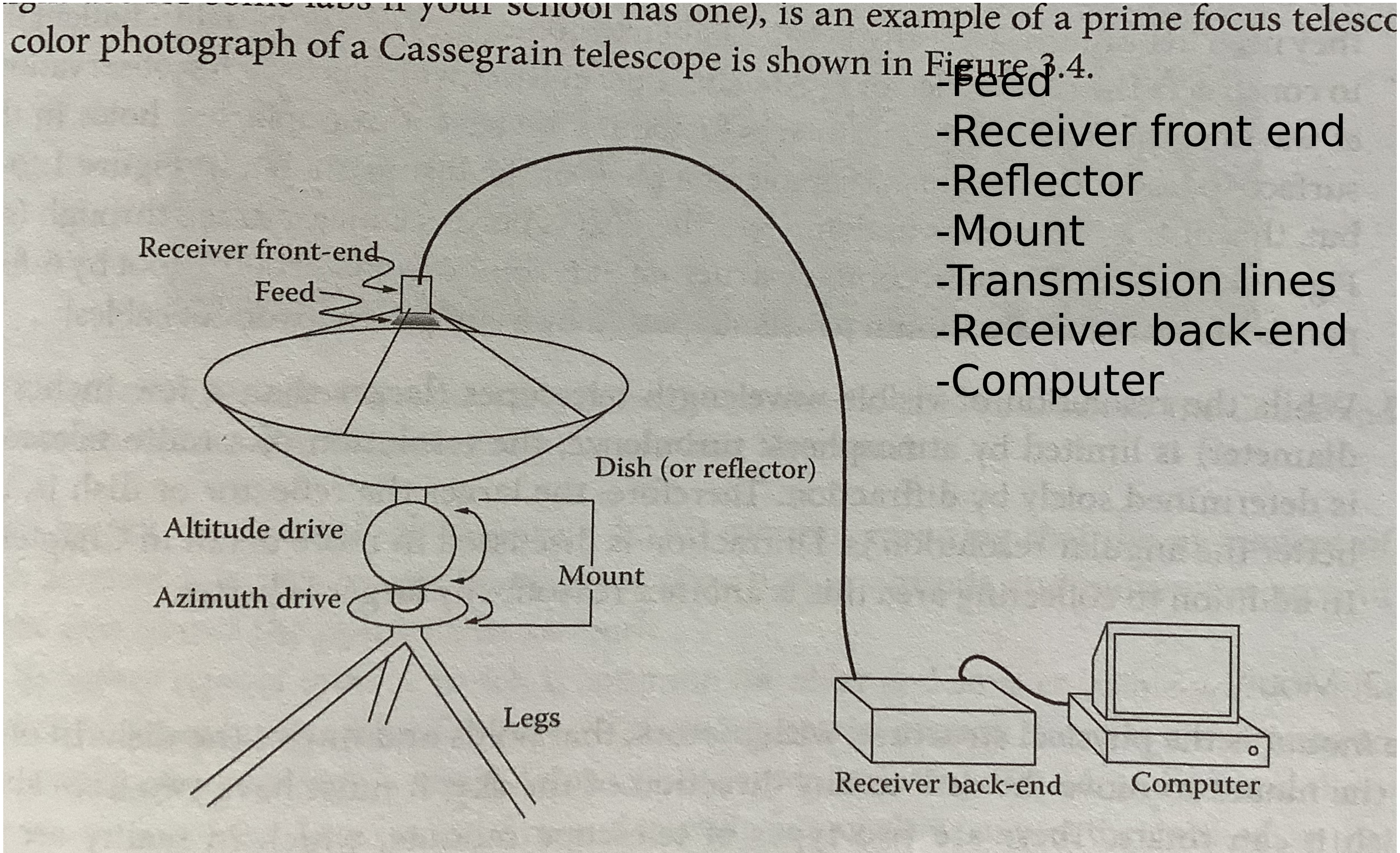
$$\frac{\nu_{\mathrm{p}}}{\mathrm{kHz}} = 8.97 \sqrt{\frac{N_{\mathrm{e}}}{\mathrm{cm}^{-3}}}$$

Ionosphere electron density ?

High frequency cut-off

Water and Oxygen molecular lines

A basic radio telescope

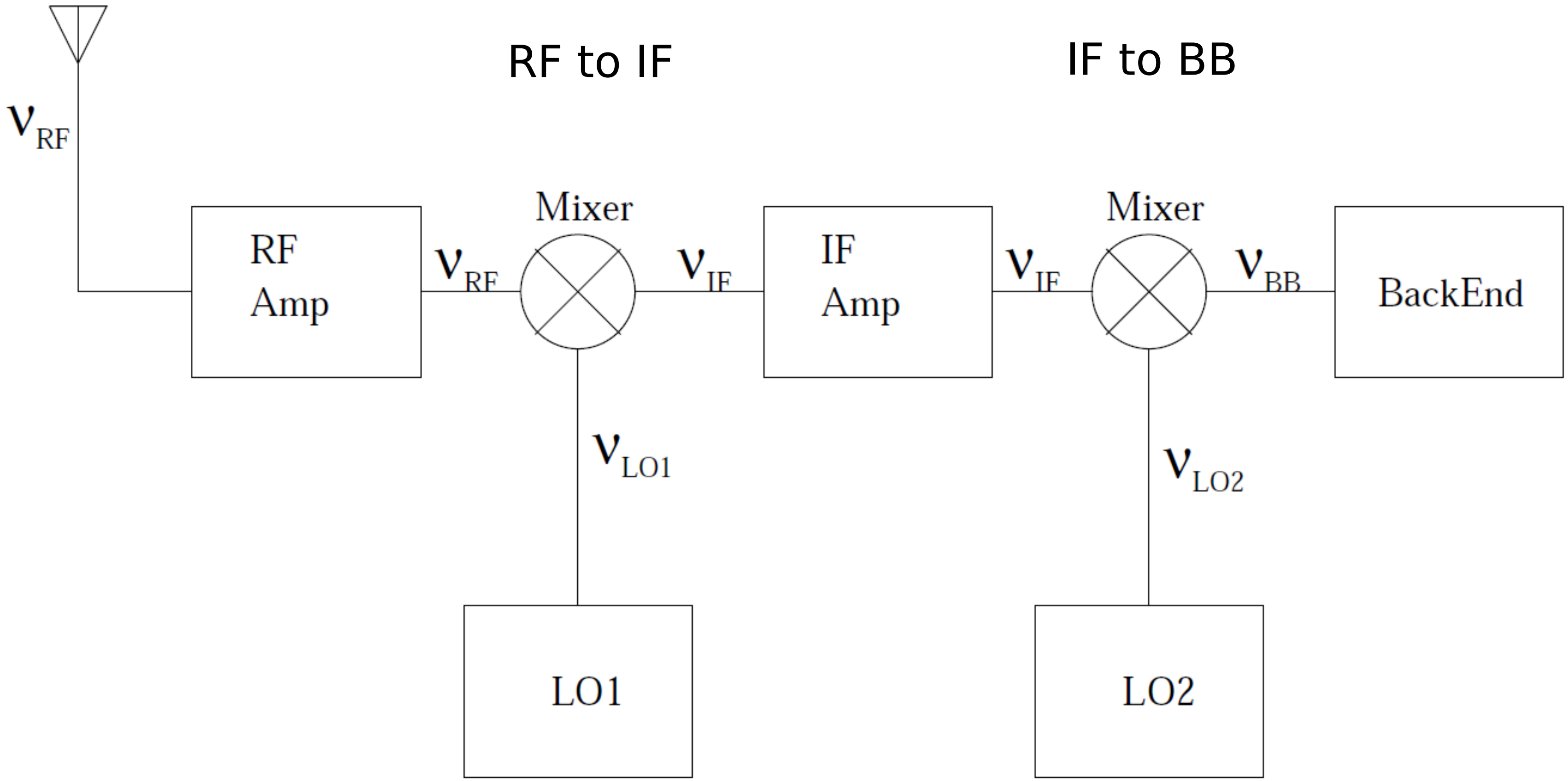


-Feed
-Receiver front end
-Reflector
-Mount
-Transmission lines
-Receiver back-end
-Computer

Radio telescope antennas

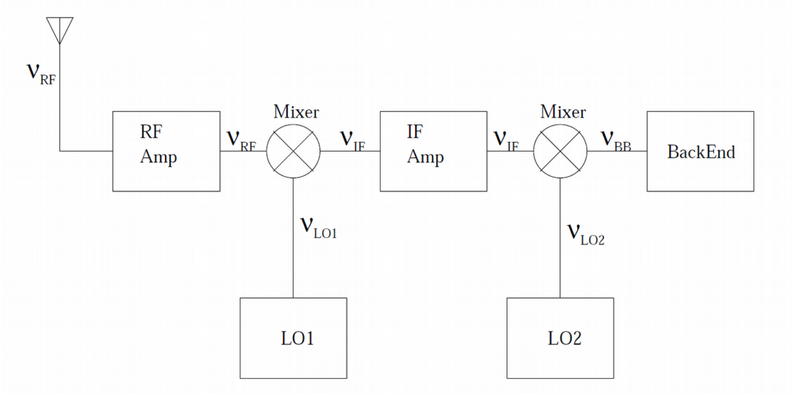
- The region of transition between a free space wave and a guided wave or vice-versa.
- For a radio telescope the antenna acts as a collector of radio waves.
- The response of an antenna as a function of direction is given by the antenna “pattern”. By *reciprocity* this pattern is the same for both receiving and transmitting.

Block diagram of a single dish radio telescope



Block diagram of a single dish radio telescope

- EM waves impinge on the antenna and create a fluctuating voltage – frequency is the same as of the incoming wave called *Radio frequency (RF)*.
- Needs *amplification*: Low noise amplifier (LNA) at the receiver front-end amplifies the signal.
- *Mixer*: changes the frequency of the incoming signal. Pure sine wave by tunable signal generator – Local oscillator (LO). Mixing – also called heterodyning.



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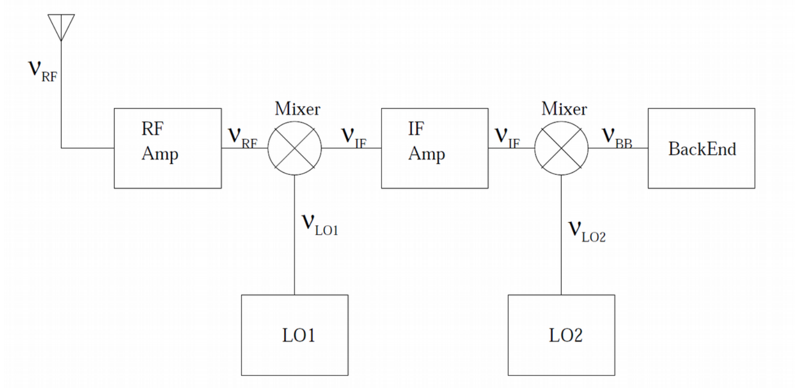
Brings the signal to an *intermediate frequency (IF)*: allows the use of same backend for a number of different frequencies observed – economical. Sometimes more mixers: IFs that minimise transmission losses and those that are optimal for best amplification – super-heterodyne systems.



GMRT LO 175 and 130 MHz IFs for two polarizations

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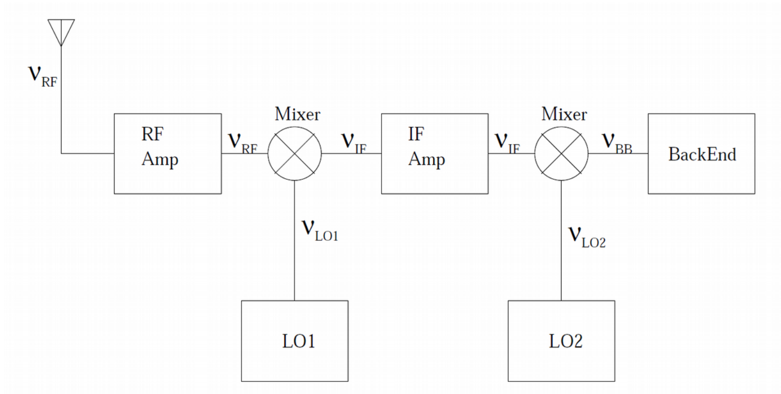


- Another stage of amplification followed by a mixer to convert the signal to *Baseband (BB)*.
- Passed to a backend: square-law detector/ correlation/ a pulsar backend

GMRT LO 175 and 130 MHz IFs for two polarizations

Effective aperture

Antenna's ability to absorb the waves that are incident on it is measured by the quantity "effective aperture", A_e.

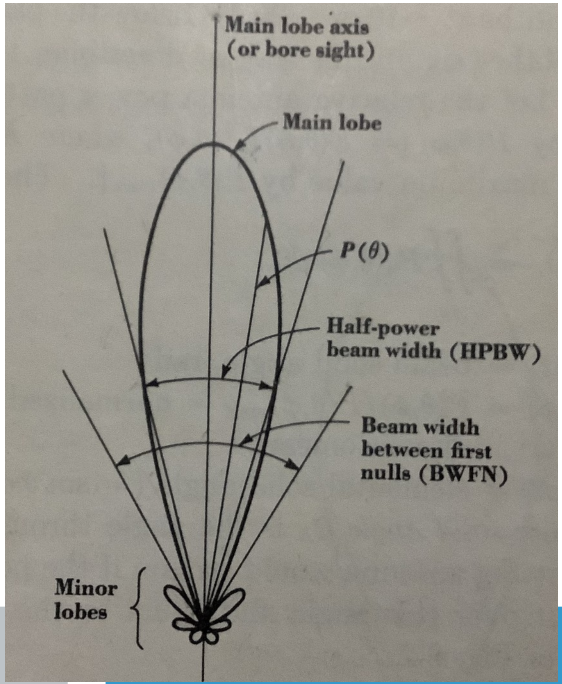
$$A_e = \frac{\text{Power density available at the antenna terminals}}{\text{Flux density of the wave incident on the antenna}} \qquad \frac{W/Hz}{W/m^2/Hz} = m^2$$

Also called effective area of the antenna. It is a function of direction, thus:

$$A_e \quad = \quad A_e(\theta, \phi)$$

The power pattern of the antenna describes the directional response of an antenna (normalized to unity at the maximum):

$$P(\theta, \phi) \quad = \quad \frac{A_e(\theta, \phi)}{A_e^{max}} \qquad \Theta_{HPBW} \sim \lambda/D$$



Directivity, gain and aperture efficiency

Another measure of the response of the antenna as a function of direction is described by "directivity":

$$D(\theta,\phi) = \frac{\text{Power emitted into } (\theta,\phi)}{(\text{Total power emitted})/4\pi} = \frac{4\pi P(\theta,\phi)}{\int P(\theta,\phi)\, d\Omega}$$

Aperture efficiency is the ratio of the maximum effective aperture and the geometric cross sectional area of the reflector:

$$\eta = \frac{A_e^{max}}{A_g}$$

Gain and directivity

Gain same as directivity but with an efficiency factor,

$$G(\theta,\phi) = \frac{\text{Power emitted into } (\theta,\phi)}{(\text{Total power input})/4\pi}\ \eta$$

Aperture efficiency,

$$\eta = \frac{A_e^{max}}{A_g}$$

Gain is often given in decibels (dB) which is:

$G(dB) = 10\log_{10}G$

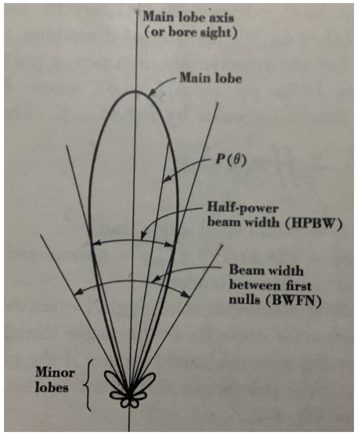
The convenience is that when there are amplifiers in succession the total gain is simply the addition.

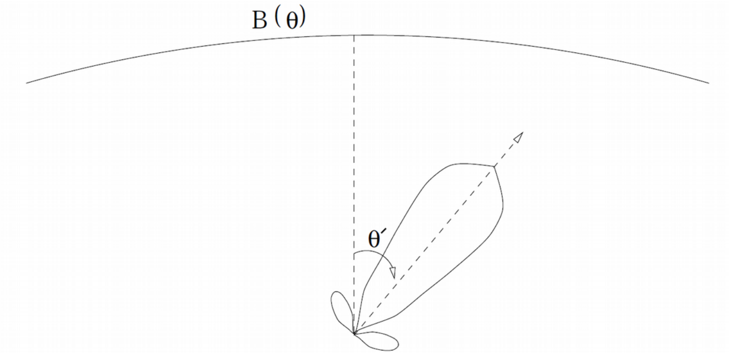
Effect of the pattern on observed sky:

Consider observing a sky brightness distribution $B(\theta)$ with a telescope having a power pattern as shown. Then the power available at the antenna terminals is:

$$W(\theta') = \frac{1}{2}\int B(\theta)A_e(\theta - \theta')d\theta$$

1-dim





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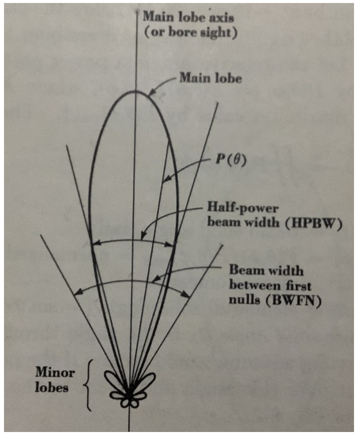
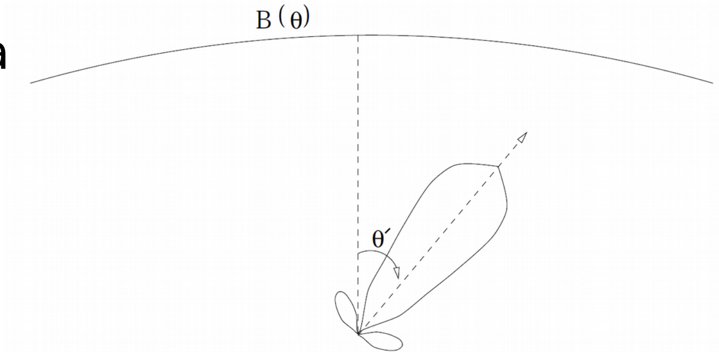
½ as only one polarization is absorbed by the antenna





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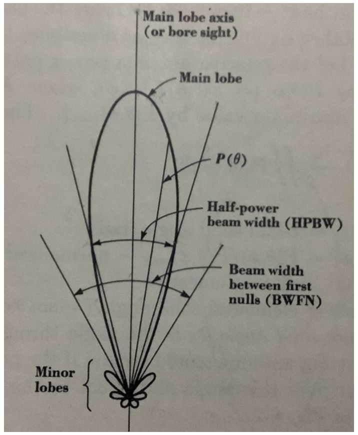
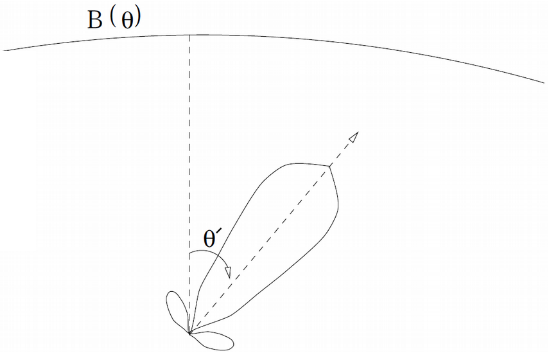
In 2-dimensions:

$$W(\theta', \phi') = \frac{1}{2}\int B(\theta, \phi)A_e(\theta - \theta', \phi - \phi')\sin(\theta)d\theta d\phi$$





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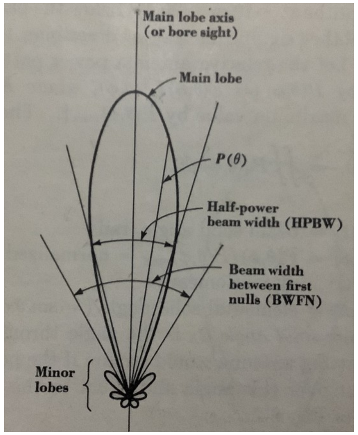

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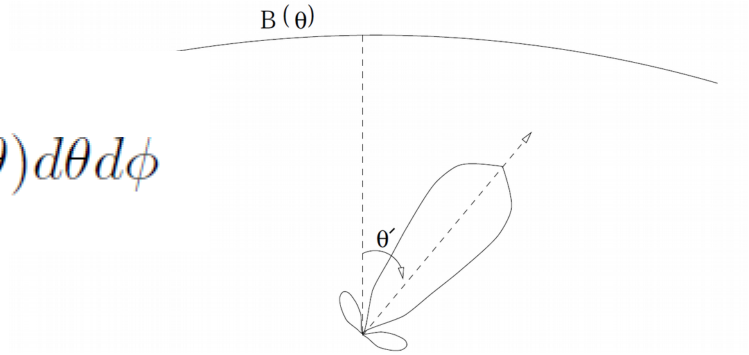

In 2-dimensions:

$$W(\theta',\phi') = \frac{1}{2}\int B(\theta,\phi)A_e(\theta-\theta',\phi-\phi')\sin(\theta)d\theta d\phi$$

In temperature units,

Recall,

w=kT

$$T_B = \left(\frac{\lambda^2}{2k}\right) B(\theta,\phi).$$

$$P(\theta,\phi) = \frac{A_e(\theta,\phi)}{A_e^{max}}$$

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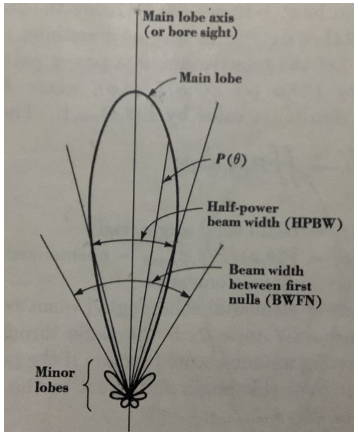

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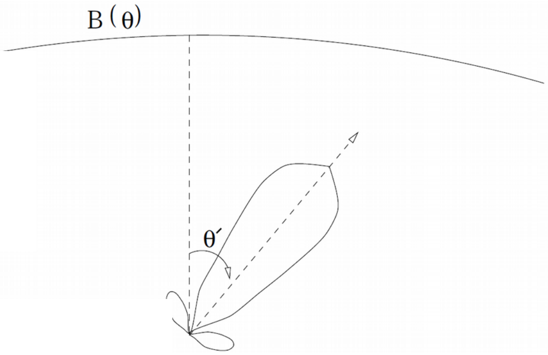

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In temperature units,

$$T_A(\theta',\phi') = \frac{A_e^{max}}{\lambda^2}\int T_B(\theta,\phi)P(\theta-\theta',\phi-\phi')\sin(\theta)d\theta d\phi$$

Antenna temperature is the weighted average of the sky temperature – the weighting function is the power pattern of the antenna.

Effect of the pattern on observed sky:

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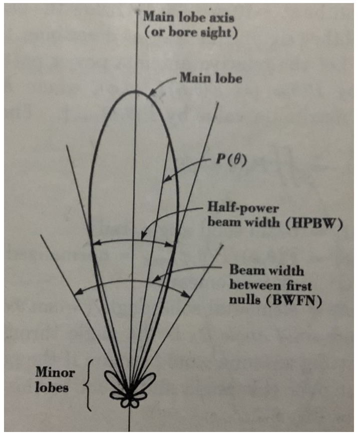

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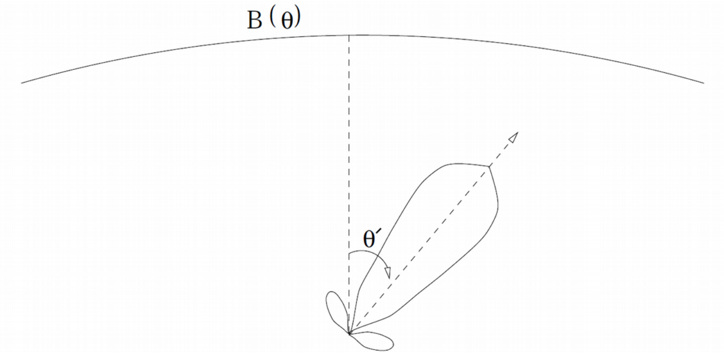
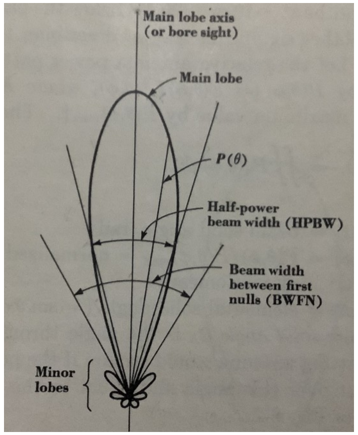


If the power pattern is a sharp spike, then the antenna temperature is the same as the sky temperature. In all practical cases antenna temperature is a smoothed version of the sky temperature.

Effect of the pattern on observed sky:

$$T_A(\theta^{'},\phi^{'}) = \frac{A_e^{max}}{\lambda^2}\int T_B(\theta,\phi)P(\theta-\theta^{'},\phi-\phi^{'})\sin(\theta)d\theta d\phi$$



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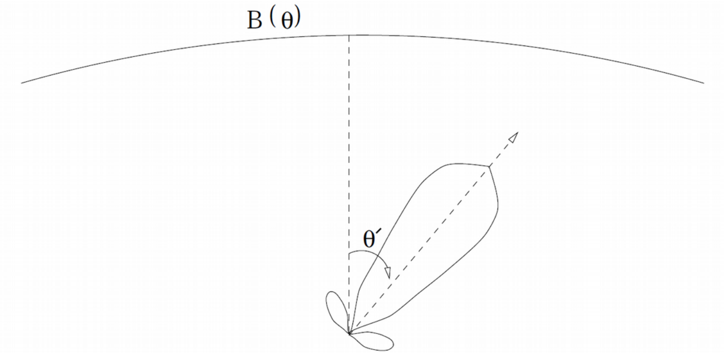

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While scanning the sky, if you observe a rise in antenna temperature, it is unclear if it is due to a single bright source or a collection of faint sources – termed as **confusion noise**.

Confusion noise is a function of frequency and the distribution of sources in the sky

Relation between directivity and effective aperture

Consider an antenna terminated in a resistor and the entire setup placed in a blackbox at temperature T. At thermal equilibrium, the power flowing from resistor to antenna is:

$$P_{R \to A} = kT$$

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$$P_{A\to R} = (\frac{A_e^{max} kT}{\lambda^2}) \int P(\theta, \phi) d\Omega$$

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Maximum effective aperture is determined by the shape of the power pattern alone.

Relation between directivity and effective aperture

For a reflecting telescope,

$$\int P(\theta,\phi)d\Omega \sim \Theta^2_{HPBW} \sim \left(\frac{\lambda}{D}\right)^2$$

And thus,

$$A_e^{max} \sim D^2$$

Recall, $$A_e^{max} = \frac{\lambda^2}{\int P(\theta,\phi)d\Omega}$$

The max. effective aperture scales like the geometric area of the reflector. Also,

$$A_e = A_e^{max} P(\theta,\phi) = \frac{\lambda^2 P(\theta,\phi)}{\int P(\theta,\phi)d\Omega}$$

$$D(\theta,\phi) = \frac{4\pi}{\lambda^2} A_e(\theta,\phi)$$

Recall: $$D(\theta,\phi) = \frac{4\pi P(\theta,\phi)}{\int P(\theta,\phi)\ d\Omega}$$

Application: Finding power at one antenna from a signal transmitted from another

Consider sending information from antenna 1 with gain $G_1(\theta,\phi)$ and input power P_1 to antenna 2 with directivity $D_2(\theta,\phi)$ at a distance R away.
The flux density at antenna 2 is:

$$S = \frac{P_1}{4\pi R^2} G_1(\theta, \phi)$$

Factor G encodes that the power is not isotropically distributed

Power available at antenna 2 is :

$$W = A_{2e} S = \frac{P_1}{4\pi R^2} G_1(\theta, \phi) A_{2e}$$

Recall: $D(\theta, \phi) = \frac{4\pi}{\lambda^2} A_e(\theta, \phi)$

After substituting for the effective aperture,

$$W = (\frac{\lambda}{4\pi R})^2 P_1 G_1(\theta, \phi) D_2(\theta^{'}, \phi^{'})$$

Friis transmission equation

Reflector antennas

The most common reflector shape is a paraboloid.

The reflector must keep all parts of an on-axis plane wavefront in phase at its focal point.